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MICROECONOMIC ANALYSIS OF MILITARY AIRCRAFT BEARING RESTORATION

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ABSTRACT

The risk and cost of a bearing restoration by grinding program was analyzed. A microeconomic impact analysis was performed. The annual cost savings to U.S. Army aviation is approximately $950,000.00 for three engines and three transmissions. The capital value over an indefinite life is approximately ten million dollars. The annual cost savings for U.S. Air Force engines is approximately $313,000.00 with a capital value of approximately 3.1 million dollars. The program will result in the government obtaining bearings at lower costs at equivalent reliability. The bearing industry can recover lost profits during a period of reduced demand and higher costs.

INTRODUCTION

Roller and ball bearing fatigue failures account for approximately ten percent of all bearing failures. The remaining 90 percent may be attributed to a variety of causes related to manufacturing flaws, human error or the effects of dirt and corrosion. Unlike fatigue failures, the other causes of failure are not subject to a tractable analytical procedure for failure prediction (ref. 1).

Those bearings removed for reasons other than fatigue failure consist primarily of component failures which affect the integrity of the bearing and consequently the integrity of the aircraft. In order to minimize risk, a subjective judgment is made to remove the bearing

and replace it. The usual procedure is to remove bearings during overhaul or other work on engines or transmissions, clean and visually inspect them for defects and dimensional conformance to print. Since most bearings are not disassembled during this operation, if there is any doubt regarding integrity, the bearing is replaced.

A pilot program was undertaken by the AVSCOM and NASA in conjunction with Industrial Tectonics, Inc. to establish the restorable yield of bearings which would be candidates for restoration by grinding (refs. 1 and 2). Using statistics obtained from the Corpus Christi Army Depot for a three month period in 1972 for the UH-1 helicopter, out of 4212 rolling-element bearings which were removed and discarded at overhaul for a calendar quarter it was probable that 90 percent or 3792 could be recovered through restoration by grinding. Extrapolating these statistics, it was further speculated that approximately one-half million dollars a year could be saved by Army aviation through bearing restoration by grinding (ref. 2). Assuming for purposes of discussion that a 90 percent recovery can be accomplished, the risk and cost of such a procedure must be analyzed.

In addition to the above, consideration should be given to the microeconomic impact of bearing restoration upon the bearing market. In the event that there is little impact upon the market, and little or no risk of using restored bearings, then a bearing restoration program would offer the government a significant cost savings over replacement of new bearings. If any of the areas produce adverse consequences, restoration still cannot be rejected, but the analysis to determine overall value becomes considerably more complicated. In this paper, an attempt will be made to determine overall value, risks and costs associated with a bearing restoration program.

PROCEDURE

The bearing restoration procedure is nearly the same procedure as the manufacturing of new bearings except that much of the work has already been performed. The process constitutes approximately the

last 30 percent of the total operations required to make a new bearing. Of considerable significance is the fact that this portion of the process is the least capital intensive since most of the forming has been done and material replacement is confined to ball or roller elements. One manufacturer's process (ref. 2) consists of a grinding operation on the outer diameter, bore, land, face, and race. Bores and OD's are ground and either thin nickel or chrome plated to restore them to original print dimensions or salvage dimensions. Inner and outer raceways are reground to a depth of 0.002 in. per surface. Since the race radii are each approximately 0.002 in. larger, the bearing must be refitted with balls 0.004 in. larger in diameter (ref. 2). The effective race curvature is identical to original dimensions within significant mathematical values. Although the bearing contains oversized balls and raceway curvatures, the geometry of the bearing is unchanged and so the stress level and estimated life will be identical to the original bearing. A similar restoration procedure applies to roller bearings (ref. 2).

The restored bearing contains new rolling elements such as balls or rollers. An advantage of regrinding the raceways is that any incipient spalls or cracks will be uncovered; in such cases the part will be scrapped.

The final aspect of the procedure is that it requires an economic lot size production run because of the set-up cost which is about $500. Although some manufacturers consider the minimum economic lot size to be about 500 bearings, the set up cost per bearing will go from $1 to $5 if only 100 bearings are restored in a single lot. For $50 OEM bearings, the $5 per bearing set-up cost may be enough to render restoration uneconomical, but for a $900 OEM bearing, the charge may not be significant. At this point an assumption will be made: it is assumed that each bearing federal stock number will constitute one potential production lot. That is, the geometry and other characteristics of a bearing are uniquely specified by a federal stock number. As a result, it is not possible to combine various bearing types to produce an economic lot size.

In order to conduct a restoration program, it would be necessary to establish several inventory policy changes. Additionally, it would be necessary to conduct annual analyses and reviews to ensure that bearing types selected for the program are being used in sufficient quantity to maintain qualification for the program. Further, consideration should be continually given to qualify other bearing types should price or quantity changes warrant their inclusion in the program. The review and analysis should be conducted by a central authority where complete records of bearing consumption are available.

The review and analysis ideally should be a two stage process; the first stage would consist of a rough screening review and the second, a detailed cost review.

The rough screening review should consist of two criteria; these being price and quantity. The simplest criteria are: if the bearing cost exceeds $50 OEM price and annual replacement is greater than 100 bearings, the bearing passes the rough screening to become a candidate for a detailed analysis. Another useful criterion would be: if the demand-price product exceeds $5000 per year, the bearing should be a candidate for a detailed analysis.

For the bearings passing the rough screening, the detailed analysis would require the following information for each bearing:

Federal Stock Number

Annual requirements for replacement

Technical Data

- Bearing Drawing
- Use
- Restoration tolerances

This information should then be sent to potential vendors with a request for quotation of prices which should include

Unit price for 60 percent return

Unit price for 70 percent return

Unit price for 80 percent return

Unit price for 90 percent return

The RFQ should stipulate that the quotes include a guarantee that the manufacturer will restore a specified fraction of the rejected bearings or incur a penalty. An example of such a penalty where the fraction restored is less than the guaranteed return is,

(1.25)×(Guaranteed fraction return minus actual fraction return)×
(number of bearings shipped to vendor)×(Prevailing scrap price)

In this case, the vendor is required to pay scrap value plus 25 percent for the difference between his guaranteed rate of restoration and the vendor's actual performance. Also, the vendor will be required to pay the prevailing scrap price on (1 - Guaranteed Fraction) of the bearings shipped to the vendor. Moreover, the unit price per bearing paid by the government would be equal to the lowest unit price of the quoted guaranteed returns. After quotations are returned, the optimal replacement policy can be determined by selecting the minimum cost for each bearing type using the expression

For a given i

$$\text{MIN } TC(i, j, GF_{ijk})$$

such that

$$\begin{aligned} TC(i, j, GF_{ijk}) = N_i\Big[&(GF_{ijk} \times UP_{ijk}) - (1 - GF_{ijk})(SV_i) \\ &+ (1 + GF_{ijk})(SC_{ij}) + (1 - GF_{ijk})(OEMP_i) \\ &+ (1 - GF_{ijk})(OEMPSC_i)\Big] \end{aligned}$$

where

i	bearing type
j	vendor
k	guaranteed fraction index (0.6, 0.7, 0.8, 0.9)
$TC(i, j, GF_{ijk})$	total cost of replacement for bearing type i, using vendor j with a guaranteed return rate k

N_i	number of bearings of type i to be shipped to vendor
GF_{ijk}	guaranteed fraction return of type i from vendor j with return index k ($k = GF_{ijk}$)
UP_{ijk}	quoted price of restoring one unit of i from vendor j with guaranteed fraction k
SV_i	prevailing salvage value of bearing type i
SC_{ij}	one way shipping cost
$OEMP_i$	original equipment vendor unit price for bearing type i
$OEMPSC_i$	shipping cost for one new bearing type i

This optimization procedure will yield the minimum cost policy for each bearing type. A sensitivity analysis should also be performed by varying the fraction returned and including the penalty function to determine the sensitivity of not meeting the vendor expected performance. In the event that the vendor exceeds promised performance, there should be no extra incentive because the vendor will be benefiting directly since the vendor is paid for each unit and the government will benefit from a lower than expected total cost.

COST EFFECTIVENESS ANALYSIS

A partial listing of annual bearing demand was obtained from the Army Aviation Systems Command. This listing included current prices and annual demand for the following

ENGINE	TRANSMISSION
T53	UH-1
T55	CH-47
T63	OH-58

Data on certain prices in effect in 1972 were also available. Table I is a comparison of these costs. Although the sample is very small and probably not statistically adequate, the information provided is worthy of

special note. During the period 1972 to 1976, the U.S. economy was subjected to a rather severe case of demand-pull inflation. The results of such inflation are that general price levels rise because the demand for goods and services exceeds the supply available at existing prices (ref. 3). Another consequence is that there are long delays for industrial and commercial deliveries and large backlogs in manufacturing plants. The backlogs may still be present in the bearing industry for some bearing types, but the large price increases are conspicuous by their absence. Reference will be made to this point again.

An analysis was conducted using the annual demand data from AVSCOM. The data are only for the three Army engines and transmissions cited above. Tables 2 and 3 show the stock numbers, annual demand, OEM price and estimated restoration price for all bearings in the data set which pass the rough screen test criterion of demand - OEM price product > $5000 per year. Table 4 is a comparison of cost differences between OEM replacement and a 0.90 fraction (90 percent) programs. The total cost savings of the 0.90 restoration program is approximately $950,000 for one year for the three engines and three transmissions in the data set. If OEM demand cost for bearings is relatively stable despite fluctuations in actual demand for specific types, then a relatively constant savings can be accomplished through bearing restoration. This value will be approximately one million dollars per year. The capital value over an indefinite life of such a program is approximately ten million dollars for the three engines and three transmissions included in this analysis.

A similar analysis was performed using data supplied by the U.S. Air Force MATP in Oklahoma City. These data appear in tables 5 and 6. The annual cost savings of bearing restoration for the Air Force engines would amount to approximately $313,000.00. The capital value over an indefinite life of such a program is approximately 3.1 million dollars.

RISK AND UNCERTAINTY

In the previous section, cost quotes by a single bearing manufacturer were used to compare the cost-effectiveness of restoration with the purchase of new bearings. The prices are sufficiently conservative whereby it would not be generally expected that these prices would be exceeded in a competetive procurement. Therefore, the cost savings associated with the price quotations would generally be more than may be actually achieved.

The major risk and uncertainty associated with the process is the reliability of restored bearings and the yield of production runs. It was assumed that a 90 percent yield could be achieved. Therefore, the cost-effectiveness analysis was performed using a 0.90 fractional yield. This basic assumption is supported by the inspection of 529 bearings comprising three bearing types from the UH-1 helicopter (refs. 1 and 2). The inspection results indicated a potential yield rate which exceeded 90 percent which supports the assumption used herein. Additional inspection data should be obtained in order to establish the confidence of the yield rate for other bearings and bearing applications.

Based upon the endurance testing reported in reference 1 for the three bearing types discussed above, the reliability of the restored bearings appears to be very similar to that of new bearings. On the basis of these results the risk and uncertainty associated with the reliability of restored bearings are no greater than those associated with new bearings. Further testing of restored bearings from other vendors should be conducted to establish the confidence of this conclusion for other restoration by grinding methods.

If one examines the failure rate as a function of time, experience should be similar to the graph in figure 1. The population will initially exhibit a high failure rate if it contains some proportion of substandard, weak specimens (ref. 4). As these components fail, the failure rate decreases rapidly during the burn-in or debugging period and stabilizes to an approximately constant value. During the useful life period, the failure rate is at its lowest level. When the components reach the life T_W,

wearout becomes noticeable and from that time, the failure rate increases rapidly. The work of reference 1 indicates that such a "bathtub function" may be applicable to restored bearings.

It is noteworthy that the only two failures which occurred out of the 90 bearings tested were attributed to the new rolling elements. These would have also failed in new bearings. The reliability of the bearing itself may be greater than that of new bearings because of the probable elimination of infant mortality of the restored bearing raceways. Such a tentative conclusion should be reinforced with additional testing of other restored bearings.

MICROECONOMICS OF BEARING INDUSTRY

The effect of implementing a bearing restoration program will primarily be a doubling of the useful life of approximately 90 percent of engine and transmission bearings in the program. An obvious question is what effect such a program will have upon the bearing industry. To answer such a question, it is necessary to delve into the microeconomics of the bearing industry. A key to answering the question lies in the behavior of prices over the period of the last several years.

From 1972 to 1976, the economics of the west were plagued with double digit demand-pull inflation. Increases in aggregate demand caused rapid price increases as the industrial sector approached maximum production levels. However, as noted previously in the small sample comparison, prices of bearings increased an average 2 percent annually. Several factors could account for such anomolous stability. If demand for bearings was lower than capacity, this situation might possibly dampen price increases because of competition and because there would be little need for capital expansion.

During this period (1972-1976) there was a gradual withdrawal from Vietnam. Therefore a decreased demand for bearings is plausible. Over a period of a couple of years, if costs were stable and demand decreased, there would be increased competition and a tendency to reduce profits for the sake of optimizing production costs. Such a conclusion

results from an examination of total production costs as a function of production rate. The elements of total cost are the total fixed costs of a facility and the total variable costs. Fixed costs are incurred from expenses for depreciation, taxes, utilities, and other indirect expenses. Variable costs are incurred from labor and materials. Total costs (TC), total variable costs (TVC) and total fixed costs (TFC) are depicted as a function of production rate (units per time unit) in figure 2.

In addition to these costs there is average cost (AC) which is total cost divided by the production rate. Average variable cost (AVC) is the total variable cost divided by the production rate; average fixed cost (AFC) is the total fixed cost divided by the production rate. If the rate of production is increased and fixed cost is a constant, then the AFC will decrease. The TVC has a tendency to increase rapidly as production is started, but will tend to level off to some extent as the optimal plant capacity is approached. When this point is exceeded, it will be necessary to add labor in the form of overtime or additional personnel and material costs will have a tendency to increase. The net effect is that there will be a point of inflection in the TVC function. Up to this point, AFC and AVC have been decreasing. Thus, the marginal cost (MC), which is the incremental cost of increasing the production rate by one unit, has also been decreasing.

Up to this point, the MC has been decreasing at a more rapid rate than AC and so it is economical to increase production. However, as MC begins to increase, there will be a point at which MC and AC are equal. It will not be economical to produce beyond this point over a long period because this will have a tendency to raise long run average costs. Simultaneously, production rates below the MC equal AC point will have a tendency to also increase long run average costs. Since it is desirable to operate near this point where AC equal MC, it may often pay to absorb some increased costs rather than to tolerate a decreased production rate. This is because these increases will have a tendency to increase the optimal production rate which will further increase the difference between the market demand rate and the optimal production rate.

If there is a marked reduction of demand in an industry, the implications of the preceding discussion are that a manufacturer will have a tendency to decrease prices and forgo some profits in order to maintain a production rate which minimizes the average unit cost. But, during the period of hypothesized demand decrease, prices for nearly all other things were increasing rapidly. During such a period the reduced market industries will have to pass through some price increases, but these increases are most likely to lag the economy as a whole.

The net effect of decreased demand is depicted in figure 3 for the time points T_1, T_2, T_3, and T_4. The slope of the price line reflects a tendency for prices to increase over time. When demand slackens at T_2, the industry will reduce prices to some extent until demand is stabilized at T_4. If prices were increasing dramatically in the overall economy and demand for a particular item slackened, the net effects would be to damper the rate of price increase for the item in question. As the industry demand stabilized, there would then be a tendency to increase prices rapidly until some lost profits were recaptured. But production rate is still down from previous levels and so the price must be increased over what would have been if the demand had not slackened (T_5). Gradually prices will stabilize at T_6, which is a level necessary to maintain previous profits.

This scenario seems to be what has happened in the bearing industry with the present time line corresponding to something between T_4 and T_5 in figure 3 if one deflates bearing prices at the same rate as for the overall economy from 1972 to 1976. If no other economic changes occur in the bearings industry economy, there should be a round of price increases coming for the industry in late 1976 or 1977. These increases may be mitigated to some extent by the lack of a need for capital expansion. As depreciation costs decrease in a depressed market, profits can be maintained to some extent.

If a bearing restoration program were implemented, the effects would be to reduce demand. This reduction could possibly coincide with the predicted price increases for late 1976 or early 1977. The net effect will be to dampen the magnitude of the increases. But eventually, the increases will come.

The total effect seen by the Army Aviation will be a net reduction in bearing expenses because of the extended life of the restored bearings. To predict within an acceptable range of uncertainty, however, would require an extensive data gathering task and a more comprehensive analysis than was presented herein.

GENERAL COMMENTS

A process of bearing restoration by grinding has been compared with new replacement of rejected bearings for three engines and three transmissions used in military helicopters. The cost advantages of using restored bearings is very significant compared to use of new bearings. The risk and uncertainty associated with using restored bearings appear to be no greater than with the use of new bearings.

A cursory analysis of the microeconomics of the bearing industry established a tentative hypothesis that the industry is being squeezed because of reduced demand and higher costs. The implication is that the industry might well be expected to raise prices in the near future. The effect of a bearing refurbishment program would be a softening of the price increases because there is equivalent profit in bearing restoration as in new bearing manufacturing. The advantage to manufacturers is the recovery of lost profits, which is essential for the maintenance of a healthy industry. The advantages of bearing restoration to the government are lower costs and equivalent reliability.

H. Hanau performed an analysis of the raw material savings associated with bearing restoration (ref. 2). The analysis predicts significant savings of critical alloying elements. The advantages to the United States are that less raw material would be used. The savings are genuine because the raw material has intrinsic value. Moreover, there is an energy utilization associated with the transformation of this raw material to the finished bearing. The value of the savings is the value of the material and energy conserved.

SUMMARY OF RESULTS

A pilot program was undertaken by AVSCOM and NASA in conjunction with Industrial Tectonics, Inc. to establish the restorable yield of bearings which would be candidates for restoration by grinding. Assuming a 90 percent bearing recovery rate can be accomplished, the risks and costs of such a procedure were analyzed. A microeconomic impact analysis of bearing restoration upon the bearing market was performed. The following results were obtained.

1. The annual cost savings to Army Aviation is approximately $950,000.00 for three engines and three transmissions. The capital value over an indefinite life of such a program is approximately ten million dollars.

2. Based upon U.S. Air Force logistic data, the annual cost savings of bearing restoration for Air Force engines would amount to approximately $313,000.00. The capital value over an indefinite life of such a program is approximately 3.1 million dollars.

3. The advantage of bearing restoration to the government are lower bearing costs at equivalent reliability. The advantage to the bearing industry is the recovery of lost profits during a period of reduced demand and higher costs.

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APPENDIX - TABLE OF SYMBOLS

AC	average cost
AFC	average fixed cost
AVC	average variable cost
GF_{ijk}	guaranteed fraction restoration of type i from j with index k
i	bearing type
j	manufacture
k	guaranteed fraction index
N_i	number of bearings of type i
MC	marginal cost
OEMP	original equipment manufacture price
OEMPSC	shipping cost of a new bearing
SC	one way shipping cost
SV	salvage value
TC	total cost
TFC	total fixed cost
TVC	total variable cost
UP	unit price

TABLE 1. - COMPARISON OF UH-1 TRANSMISSION BEARING

COSTS DURING 1972 AND EARLY 1976

Federal stock number	1972 price, $	1976 price, $	Annual rate of price increase, %
3110-00-133-3378	56.98	69.07	5
3110-00-133-3379	219.00	233.00	1.5
3110-00-135-2603	334.00	365.00	2.2
3110-00-199-7398	50.83	50.83	0

TABLE 2. - 1975 U.S. ARMY AVIATION ENGINE BEARING DEMAND AND PRICES

Federal stock number	Annual demand	OEM price, $	Restoration price, $
T53 engine			
3110-00-727-3032	516	64.65	38.00
3110-00-995-8007	108	60.46	35.00
3110-00-071-4568	552	90.20	43.00
3110-00-421-1814	315	51.18	30.00
T55 engine			
3020-00-986-0441	684	53.56	32.00
3020-00-986-0443	972	77.18	41.00
2840-00-986-0444	1416	75.48	40.00
3110-00-116-5534	96	389.00	152.00
3110-00-106-5798	48	136.00	70.00
T63 engine			
3110-00-426-1195	840	58.30	35.00
3110-00-199-7398	1488	50.83	30.00
3110-00-133-3379	564	233.00	100.00
3110-00-135-2603	636	365.00	130.00
3110-00-133-3378	504	69.07	32.00

TABLE 3. - 1975 U.S. ARMY AVIATION TRANSMISSION BEARING DEMAND AND PRICES

Federal stock number	Annual demand	OEM price, $	Restoration price, $
OH-58 transmission			
3110-00-426-1210	144	153.00	77.00
3110-00-400-2786	264	359.00	130.00
3110-00-179-7297	170	108.00	50.00
3110-00-179-7299	96	82.10	42.00
3110-00-132-1049	336	61.53	36.00
CH-47 transmission			
3110-00-060-7965	10	853.00	330.00
3110-00-856-6608	29	660.00	260.00
3110-00-155-4212	72	135.00	70.00
3110-00-051-5627	144	824.00	300.00
3110-00-057-8306	33	337.00	132.00
3110-00-828-5174	72	331.00	130.00
3110-00-984-0276	96	641.00	250.00
3110-00-060-7911	84	101.00	50.00
3110-00-913-4203	42	142.00	73.00
3110-00-836-0451	64	500.00	205.00
3110-00-833-9082	72	105.00	48.00
3110-00-014-2055	25	351.00	138.00
3110-00-946-0546	24	265.00	104.00
3110-00-946-4876	25	351.00	138.00
3110-00-067-8289	60	84.51	43.00
3110-00-052-0392	20	268.00	115.00
3110-00-066-5286	48	305.00	120.00
3110-00-052-0393	24	255.00	100.00
UH-1 transmission			
3110-00-199-7398	1488	50.83	30.00
3110-00-133-3379	564	233.00	100.00
3110-00-135-2603	636	365.00	130.00
3110-00-133-3378	504	69.07	32.00

TABLE 4. - ARMY OEM VS. 90% RESTORATION FOR 1975

	OEM repl. cost, $	Restoration cost, $
T53 engine	105 801.18	61 543.62
T55 engine	262 405.68	149 045.70
T63 engine	522 970.32	258 650.37
OH-58 transmission	163 723.68	79 309.02
CH-47 transmission	361 643.60	165 039.06
UH-1 transmission	473 998.32	227 293.17
Total	1 890 542.78	940 880.94
Difference	949 661.84	

TABLE 5. - ENGINE BEARING DEMAND AND PRICES FOR 1976 FOR U.S. AIR FORCE

Federal stock number		OEM price, $	Annual demand	Restoration price, $
TF33	3110-00-868-2741RU	151.00	40	77.00
	3110-00-830-1694RU	444.20	24	173.00
	3110-00-007-6910RV	163.92	72	84.00
	3110-00-858-2683RV	394.50	60	154.00
	3110-00-103-7248RV	222.50	68	108.00
	3110-00-858-2659RV	660.30	72	258.00
	3110-00-868-2742RV	210.90	68	97.00
	3110-00-864-9269RV	446.20	64	174.00
	3110-00-864-9404RV	210.30	80	96.00
TF30	3110-00-182-8078PQ	427.93	136	167.00
	3110-00-274-9830PQ	493.62	176	193.00
	3110-00-412-0498PQ	1093.96	200	427.00
	3110-00-881-4810PQ	253.20	84	116.00
	3110-00-412-3449PQ	352.27	64	137.00

Source: Letter dated 3 May 76: E. L. Ansley, Chief of Production Branch U.S. Air Force MATP, Oklahoma City, Oklahoma.

TABLE 6. - AIR FORCE OEM VS. 90% RESTORATION FOR 1976

	OEM replacement cost, \$	.90 restoration cost/.10 OEM replacement, \$
TF33 engine	174 566.64	83 556.26
TF30 engine	407 671.68	185 299.97
Total	582 238.32	268 856.23
Difference	\$313 382.09	

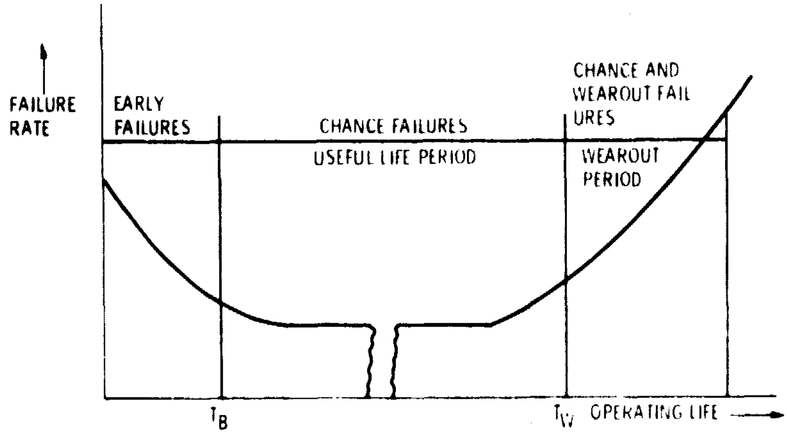

Figure 1. - Component failure rate as a function of age.

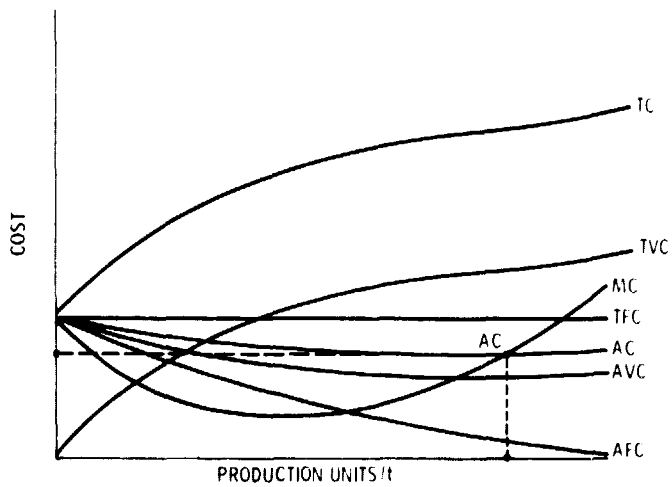

Figure 2. - Cost as a function of production rate.

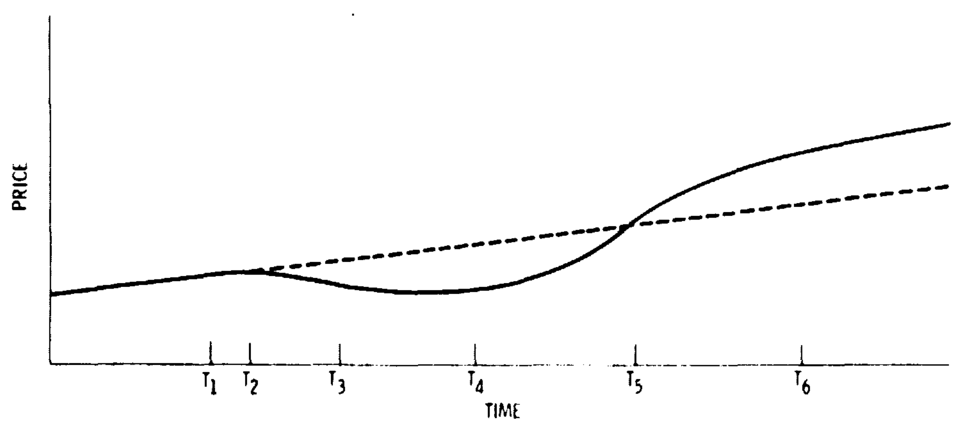

Figure 3. - Effect of decreased demand upon prices in a stable economy.

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